Remarks

A marked up version showing the amendments is attached hereto.

The applicants are submitting herewith formal drawings correcting the informalities noted by the Examiner. In particular, the diode in Figure 2 has been referenced 86 in the drawings and where referred to in the specification. The reference sign 13 has been added. Also, the wetting layer was shown, but not referenced. It has now been specified that the quantum dot layers 10, 14 consist of wetting layers 70, 71 and quantum dots 73, 72. It is believed that these amendments overcome the Examiner's objections to the drawings.

The problem facing the inventors was the production of a laser tunable over a wide range of wavelengths. The present invention is tunable over 100's of nanometers, whereas the prior art was typically tunable over a few tens of nanometers (see line 16, page 1 of the specification).

The inventors have discovered that if low dimensional quantum structures, i.e. quantum dots or quantum wires, are used in a laser diode it is possible to construct a laser that, when used in an external cavity configuration, will be tunable over 100's of nanometers. This result is achieved in part because the number of states of these structures is orders of magnitudes of smaller than for quantum wells. As a result it is possible to achieved population inversion for a large number of wavelengths. This would result in discrete spectral lines. However, when self-assembled quantum dots are employed, the inventors have discovered that there is an interaction between the quantum dots that results in a broadening of the spectral lines so that the device emits continuously (i.e. not in a discrete fashion) over a wavelength several hundred nanometers wide. When such a laser source is used in an external cavity laser, the result is a laser capable of being tuned over a wide range of wavelengths. Such a device was not known in the prior art.

Cook teaches, in passing, an external cavity laser. However, it should be noted that Cook's teachings do not relate to external cavity lasers <u>per se</u>. Cook is concerned <u>with anti-reflection</u> coatings for an optical element (See introduction and the majority of the specification). Cook teaches that quantum wells can be employed in the laser diode. Such structures were intended to be excluded by the definition to be found at lines 3, 4 page 2,

where low dimensional structures are defined to exclude quantum wells. The applicant is permitted to be his own lexicographer. However, quantum dots and quantum wires have now been expressly claimed in claim 1 as part of a Markush group.

Although Cook in passing refers to a tunable laser, anyone experimenting with Cook would find that the wavelength range covered is very small (few tens of nanometers at the most), and indeed his use of a 2-layer anti-reflective coating would not have sufficient bandwidth to cover the wavelength range of the invention. There is nothing to suggest in Cook that it could or should be used as the starting point in a quest to make a laser tunable over 100's nanometers. On the contrary, Cook's disclose of a 2-layer anti-reflective coating suggests a very narrow tunable range.

Osinski on the other hand has nothing to do with tunable lasers. It teaches how to construct a spatially broad area laser. "The end goal is to obtain a high efficiency, high power, broad area semiconductor laser with diffraction limited convergence of the output laser beam" (see col. 3 lines 50-52). This goal is achieved by the use of anisotropic waveguides as particularly described by Oskinski. In the context of such lasers, Osinski gives a generic shopping list of possible sources including quantum well layers, quantum wires or quantum dots without giving any indication that there is any significant difference in properties between quantum wells, quantum dots and quantum wires. Consequently, even if it were assumed *arguendo* that the inventor started from Cook and found the wavelength range too restrictive using the quantum wells suggested by Cook, there would be nothing to motivate the inventor to select quantum dots or quantum wires from the shopping list provided by Osinski that includes quantum wells to address the problem of the narrow tunability range. On the contrary, the manner in which Osinski discloses quantum dots and quantum wires as part of a shopping list suggests that he considers them equivalent and the inventor could not expect to find any improvement based on Oskinski's teachings. Furthermore, the choice of such materials quantum wells, quantum wires, and quantum dots, is not even specifically related to the invention disclosed by Oskinski, namely the production of a broad area laser. So even if a person skilled in the art did hypothetically seek to modify Cook to improve the spatial area, he would only need to import the anisotropic waveguides taught by Osinski as achieving this

result. He would have no motivation to change the quantum wells taught by Cook for the quantum dots included in Oskinski's shopping list.

The Examiner, aware that the courts require a motivation for combining references, has suggested a motivation totally outside the field of the applicant's endeavour. However, the courts have warned that such an approach must be used with caution. It is very artificial, and nearly always based on hindsight, to suggest that where an inventor has solved an important problem in the art, tunability range of lasers, such as solution is obvious because for reasons totally unrelated to the invention one skilled in the art might have been motivated to combined the references. Having established that a reference must be "reasonably pertinent" In re Wood, 202 USPQ 171, the courts have stated:

> [a] reference is reasonably pertinent if ... it is one which, because of the matter with which it deals, logically would have commended itself to the inventor's attention in considering the problem...If a reference discloses the same purpose as the claimed invention, the invention relates to the same problem... [I]f it is directed to a different purpose, the inventor would accordingly have less motivation or occasion to consider it. *In re Paulsen*, 31 USPQ 2s 1671. (emphasis added)

Spatial broadening has nothing whatsoever to do with providing tunability over a wide range (100's of nanometers). There is no suggestion in Cook that there is a need to increase the area. Furthermore, there is no suggestion in Osinski the choice of quantum dots or quantum wires improves tunability, or even improves the result Oskinski is seeking, namely better spatial broadening.

The applicant has specified in claim 1 that the structures are self-assembled. It is possible from an examination of the product to determine that the structures are self-assembled, and such a limitation is therefore perfectly acceptable. The same reasoning applies to amended claim 5. It is possible by inspection to identify "quantum dots obtained by spontaneous island formation during epitaxy of highly strained semiconductors" and therefore such a limitation is acceptable in the claim. Such as process limitation is only unacceptable when the resulting element is indistinguishable from an element made by a different process. Furthermore, in *In re Luck* 177USPQ 523 the following amendment was found acceptable by the CCPA:

> "said coating having been affixed to said glass member by applying thereon a liquid organic solvent having dissolved therein said polymer"...

It is not true therefore that a process limitation can *never* limit an element in a product claim.

Regarding claim 6, the Examiner finds it necessary to combine three references, non of which is directly related to the applicant's field of endeavour. Romano is concerned with the growth of quantum wells, which are excluded from the applicant's invention. Romano has nothing to do with tunable lasers, nor does it in any way teach a laser source having a wavelength range extending over 100's nanometers. Clearly, Romano does not teach a wetting layer in associate with quantum dots, and which in accordance with the invention is tied to the spontaneous island formation that results in a device emitting over a very broad spectral (to be distinguished from spatial as taught in Osinski) range.

With reference to claim 8, the Examiner's position, in the applicant's respectful submission, becomes even more tenuous as the Examiner has to combine no less than four references, not one of which relates to the applicant's field of endeavour, namely broad spectral range tunable lasers. Such an alleged allegation of prima facie obviousness is, in the applicant's respectful permission, based on an improper use of hindsight using the applicant's teachings as a blueprint to reconstruct the invention from the prior art.

In summary, with regard to claim 1, neither reference has anything to do with the applicant's field of endeavour, which is to improve the tunability range of a tunable laser. Neither reference would suggest itself to the inventor as offering any assistance in solving this problem, not would it suggest that such an improvement could be achieved by using self-assembled quantum dots or wires. On the contrary, the only reference to quantum dots and quantum wires is to be found in Osinski, and this suggests that there is no difference in result. Consequently, even if hypothetically one skilled in the art were is some way motivated to modify Cook by incorporating the teachings of Osinski "for the purpose of obtaining a high efficiency broad area laser", since the teaching of Oskinski is that this result is achieved by the use of an anisotropic waveguide, there would be nothing to motivate the person skilled in the art to exchange the quantum wells taught by Cook for the additional options, namely quantum dots and quantum wires, taught by Oskinski. Based on the teachings of the two patents, nothing would be gained by such an exchange, so what would motivate the person skilled in the art to depart from the teachings of Cook so far as the lasing medium is concerned. Such an artificial attempt to reconstruct the

applicant's genuine invention from two prior art references that have nothing to do with the applicant's field of endeavour is highly artificial and based on the impermissible use of hindsight.

The Examiner is therefore respectfully requested to reconsider his rejection to the amended claims in the light of the above comments.

It is believed that this application is in condition for allowance and reconsideration and allowance are respectfully requested.

Respectfully submitted

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Marked-up Version Showing Amendments

Fig. 1 shows a schematic for the quantum dot laser diode portion of the QD-TEC laser in accordance with the invention. Such a diode comprises multiple layers of semiconductor materials which are depicted in the upper part of fig. 1, together with the corresponding energy band diagram shown in the lower part of fig. 1. In the band diagram, the vertical direction represents the energy of the carriers in the structure, and the horizontal direction represents the position of the carriers within the laser structure. The quantum dot layers 10, 14 are very thin; for instance in a preferred form of the device, the thickness of a quantum dot 72, 73 together with the wetting layer71, 70 which forms below the quantum dots ~~10, 14~~72, 73 is about 4.5 nanometers or smaller. Hence, it is necessary to provide a substrate to grow the layers and to give structural integrity to the device. The substrate can be electrically conducting or insulating, and will typically have a thickness between 0.1 and 1 mm. The substrate will preferably be covered with a buffer layer which also serves to initiate proper growth conditions during the epitaxy.

In particular, the amount of semiconductor material required to form the self-assembled quantum dots (~~10~~72, ~~14~~73, etc.) depends on the relative strain between the substrate and the quantum dots. The number of quantum dots per unit area can be adjusted by varying the amount of material deposited in the quantum dot layers. The size of the quantum dots can be adjusted from the substrate temperature used during the growth of each quantum dot layers. For example, in the exemplary embodiment, due to the small size of the quantum dots, quantum mechanics will dictate the values of energy levels (30, 32, 34, 36, 38, 50, 52, 54, 56, 58) localized in the low band gap material (68) by the barriers (9, 12, 15). The shape of the zero-dimensional potential gives rise to a series of discrete, atomic-like, energy levels for the electrons s_e, p_e, d_e, f_e, g_e (30, 32, 34, 36, 38 respectively), and for the holes s_h, p_h, d_h, f_h, g_h (50, 52, 54, 56, 58 respectively), below the wetting layer subband WL_e (40) and WL_h (60) for the electrons and holes respectively. For self-assembled quantum dots, the degeneracy of these levels is typically 2n where n is the index of the level with, n= 1 for the ground state S, n= 2 for the first excited state P, etc. where the factor of 2 comes from the spin degeneracy, and the factor n originates from the various allowed angular momentum. The self-assembled quantum dots

effectively give a zero-dimensional potential with a quasi-parabolic confinement, and consequently the energy spacing between the adjacent levels (also called the intersublevel spacing) is roughly constant for the various levels.

The number of allowed energy levels and intersublevel spacing is determined by the shape and size of the quantum dot, the height of the confining potential between the barriers (9, 12, 15) and the quantum dot layers (10, 14), and by the carrier effective mass. Experimental assessment of these energy levels can be obtained independently by probing the interband transitions and observing the state filling in photoluminescence or electroluminescence. The carriers introduced by the carrier injection fill the quantum dot energy levels in accordance with the level degeneracy, a rule similar to the atomic Hund's rule for filling orbitals, and Coulomb interaction and renormalization energies. For example, first the ground states s_e (30) or s_h (50) can each accommodate 2 carriers, one spin up, and one spin down, then the first excited states p_e (32) or p_h (52) can accommodate 4 carriers 2 spin up and 2 spin down, etc. The total number of available states is therefore given by the number of states per QDs for the energy range of interest, taking into account the degeneracy of the levels, multiplied by the density of QD in the layers which can be varied between 10^8 to 10^{10} cm^{-2}. This is typically about 2 orders of magnitude lower than for 2-dimensional quantum well structures, and therefore it is possible to saturate the states over a much wider energy range for the quantum dot laser diode.

Fig. 2 illustrates an example of how an external cavity and a wavelength-selective element can be configured to tune the output wavelength of the QD-TEC laser. The quantum dot laser diode ~~36~~ 86 is aligned between reflectors 30 and 32, the wavelength-selective element 34 discriminate the optical path of the various wavelengths. Optical elements ~~36~~86, 38 can also be used to determine the beam path outside the laser diode cavity 40, and to initiate the waveguiding inside the laser diode cavity 40. Several configurations are possible, but fig. 2 exemplifies one of the possible embodiments using a diffraction grating for the wavelength-selective element 34. For such an embodiment, the optical element ~~36~~86, 38 will preferably be lenses used to provide the desired optical characteristic and mode profiling functions, and to collimate the photons existing the laser diode. One side of the collimated beam 44 is incident on the diffraction grating 34 and at

an angle θ. The grating then disperses the light mainly in a preferred intensity ratio between a zero-order diffraction 46 and a first-order diffraction 48. The wavelength in the zero-order diffraction are not dispersed and this beam 46 can be used as the (or one of the) output beam of the QD-TEC laser. The wavelengths in the first order beam 48 are dispersed in space and a spatial filter 50 can be used to let only the desired wavelengths resonate in the cavity. The wavelength tuning can be achieved by turning the grating angle θ or preferably by displacing the spatial filter 50, either of which will vary the wavelength bandpass which is allow to resonate in the cavity. The adjustment of the tuning element can be made with the help of some mechanical components or some electro-optical actuating devices which can be calibrated and/or computerized.

Also as mentioned above, fig. 2 exemplifies one of the many possible embodiments, and for example in some embodiments, it might be preferable to build the wavelength-selective tuning element integrated to the QD laser diode by using lithography techniques to produce gratings directly on the semiconductor, and which could be tuned using electric fields and/or currents in part of the device. Also, in some embodiments, it might be preferable to build part of the external cavity integrated to the QD laser diode and/or to the wavelength selective tuning element. For example, the reflector 30 and the optical element ~~36~~ 86 are preferably eliminated by producing a reflector with the appropriate optical properties directly on the laser diode facet 64 using a combination of deposited thin films. Similarly the optical properties of the facet 62 can be adjusted by depositing thin films to optimize the device performance. Also the reflector 32 can be eliminated by folding the first order beam 48 directly back on the laser diode beam 66. The preferred geometry and the optical properties of the various elements will be dependent of the desired tuning range and power, and the desired spatial, temporal, and spectral mode profile for the QD-TEC laser. For example, the reflectivity and the transmission spectra of the reflector 30 and 32, and/or of the facet 60 and 62, as well as the grazing angle of the grating 34, will have to be adjusted according to the wavelength range of the QD-TEC laser

Fig. 3 demonstrates the case for a quantum dot laser diode having seven layers of InAs quantum dots (~~10~~72, ~~14~~73, etc.) with GaAs barriers (9, 12, 15, etc.), with $Al_{0.35}Ga_{0.65}As$ barriers (8, 16), and with $Al_{0.7}Ga_{0.3}As$ electron (4) and hole (20) emitting

layers barriers, grown on a GaAs substrate which is part of the contact layer 30. For this example, the metal contact (58 in fig. 2) is 60 micron wide and 5mm long on top of GaAs contact layer (22). Cleaved facets with no facet coatings (60 and 62 in fig. 2) are used here. The resulting 0-dimensional transition (S, P, D, F, and WL) can be observed at the bottom of fig. 3 in the electroluminescence (EL) and photoluminescence (PL) spectra obtained at different excitation intensity and current. The top of the fig. 3 demonstrates lasing at lambda ~ 965nm, in the lower zero-dimensional states, at a wavelength about one hundred nanometers away for the shortest achievable wavelength which would correspond to the wetting layer (WL) transitions. The threshold current density to obtain lasing in this case is 13.5 A/cm^2, resulting in a range of saturated zero-dimensional states, and a range of saturable zero-dimensional states as indicated.

Claims

I claim:

1. A laser system comprising a laser diode with a multitude of self-assembled low dimensional quantum structures organized to ~~for~~ emit~~ting~~ light continuously over ~~a wide range of~~ a wavelength range of hundreds of nanometers~~wavelengths~~, said quantum structures being selected from the group consisting of quantum dots and quantum wires, a wavelength-selective element for selecting a wavelength of interest emitted by said laser diode, and an external cavity resonant at a wavelength selected by said wavelength-selective element so that the system generates laser light at said selected wavelength.

5. The laser system of claim 1, wherein ~~the~~ said low-dimensional structures are quantum dots obtained by spontaneous island formation during epitaxy of highly strained semiconductors.~~produced using self-assembly growth methods.~~